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SOME RESULTS OF INVESTIGATIONS IN THE SOVIET UNION OF THE UPPER ATMOSPHERE AND COSMIC SPACE DURING THE IGY WITH THE HELP OF ROCKETS AND SATELLITES

(A REVIEW)

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SOME RESULTS OF INVESTIGATIONS IN THE SOVIET UNION OF THE UPPER ATMOSPHERE AND COSMIC SPACE DURING THE IGY WITH THE HELP OF ROCKETS AND SATELLITES

(Nekotoryye itogi issledovaniya
verkhney atmosfery i kosmicheskogo prostranstva
pri pomoshchi raket i sputnikov
v techenii MGG v Sovetskom soyuze)

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by V. V. Mikhnevich

Among observations carried out according to the IGY program in 1957-1959, a large share belonged to investigations of the Earth's upper atmosphere.

The utiliztion of rockets and satellites permitted the study of properties and physical phenomena not only of the upper atmosphere, but also of interplanetary space and of the Moon.

As is well known, every rocket experiment provides a vertical cross section of the atmosphere. During the launching, the variation of one or another atmosphere property is studied in height at a given geographic point at a given moment of time.

Investigations on a satellite allow the obtention of data on latitude, daily, seasonal variations of the state of the atmosphere. Only a coordination of rockets and satellites provides the possibility to study to the fullest of properties of the upper atmosphere.

Nearly every experiment on rocket and satellite set up during the IGY, provided new, unique data.

The fundamental problems of the upper atmosphere were solved as a result of investigations conducted by Soviet scientists. The geophysical and space investigations were conducted in the Soviet Union along the following basic directions :

1) structural parameters of the atmosphere (pressure, density, temperature and atmosphere composition) ;

2) ionization of the ionosphere and of the interplanetary space (concentration of positive ions, electrons, composition of ions);

3) Magnetic fields of the Earth, of the Moon and of the interplanetary space;

4) cosmic radiation;

5) ultraviolet, X — and corpuscular radiations of the Sun, diurnal sky luminescence and night-sky glow;

6) meteor matter.

Contrary to the investigations carried out in the U.S.A. the study of the upper atmosphere and of the interplanetary space in the Soviet Union was as a rule conducted in a complex fashion. Particularly interesting proved to be the investigations achieved on the third artificial satellite of the Earth (Sputnik III), where a broad program of observations was set up, and where nearly every experiment was completed and verified by another one. Such character of investigations has a considerable advantage by provoding the possibility of a more reliable and full interpretation of the obtained results, and of establishing the interrelation between the various processes.

175 rockets were launched during 1957 — 1959, of which 158 were meteorological and 17 — geophysical. The launchings took place in middle latitudes of the European SSSR, on the Francis Joseph land (Heiss island), and aboard sea-going vessels at various latitudes from Antarctica to the northern part of the Pacific Ocean [1].

During these launchings spherical containers were applied at first; they were self-orienting — and also the retrievable cylindrical containers with an oscillographic recording of the scientific instrumentation's readouts.

The weight and shape of the containers and their complexion were quite varied. But their common characteristic was the weight and the volume, both rather great, and providing the possibility to install within them of a large and complex instrumentation, thus conducting investigations according to a broad program.

Thus, the spherical container weighs near 400 kg, with a diameter of about one meter. 15 — 20 experiments are achieved by means of that container.

In geophysical rockets the apparatus is installed in the rocket itself, in its upper part consisting of a container of various shapes (spherical, conical etc..), and also in cylindrical containers disposed in mortars on the side of the rocket [2].

Biological investigations were also conducted with the aid of geophyscial rockets. Animals and the appropriate instrumentation were disposed in hermetically-sealed cabins.

The salvaging of animals and containers was realized by means of parachute systems.

At launchings to 210 km, the total weight (payload) of the scientific instruments and animals reached 2200 kg, to 500 km — 1520 kg. In the latter case, the rocket orientation was stabilized during the whole flight.

Aside from geophysical and meteorological rockets, the investigation of the upper atmosphere in the Soviet Union was also conducted with the help of artificial satellites of the Earth, of cosmic rockets and spaceships.

The launching on 4 October 1957 of the first Earth's artificial satellite "Sputnik I" was not only a revolution from the standpoint of rocket technique. It opened for all world scientists broad perspectives for further investigations.

On 3 November 1957 Sputnik II was put into orbit, and on 15 May 1958 — an enormous cosmic laboratory — Sputnik III — rose to 1880 km and completed a broad program of geophysical studies.

Together with the increase in apogee (Sputnik I —900 km, Sputnik II — 1650 km, Sputnik III — 1880 km), and of the weight (Sp. I — 83.6 kg, Sp.II — 508 kg, Sputnik III — 1327 kg), the program of scientific investigations was broadened considerbaly between the first and the third sputniks.

The following basic problems were set up before Sp. I:

1) reaching the first cosmic velocity ; 2) study of radio-wave propagation through the ionosphere) ; 3) determination of atmosphere density by sputnik deceleration ; 4) determination of the satellite's thermal regime.

Aside from that, the influence of conditions of space flight (load factor at blast-off, weightlessness in flight, effect of solar and cosmic radiation etc..) on the vitality of organisms, and also the determination of cosmic and solar radiation, constituted problems set up before Sputnik II.

Sputnik III constituted the most complex laboratory, equipped with a contemporary scientific research apparatus for conducting a broad complex of atmosphere investigations.

To measure positive ion concentration in the atmosphere above sputnik's surface, two latticed ion traps were installed, and the determination of the composition of positive ions in the ionosphere was conducted with the aid of a radio-frequency mass-spectrometer.

The space distribution of the constant geomagnetic field at great heights was investigated by means of a special magnetometer.

A cosmic ray counter registered the variation of intensity and the energy spectrum of cosmic radiation.

Electrostatic fluxmeters measured the Earth's electric field along Sputnik's trajectory.

The hard component of primary cosmic radiation was studied with the help of a Čerenkov particle counter.

Magnetic and ionization gages determined the atmosphere density. Piezoelectric pickups registered the number of collisions and the energy of micrometeors.

A varied instrumentation assured the transmission of the obtained measurements to ground, the determination of Sputnik's trajectory, the thermoregulation etc..

The scientific investigations conducted on rockets and satellites provided the possibility for Soviet scientists of being prepared for the realization of cosmic flights and the reaching of other planets of the solar system.

On 2 January 1959 the launching of a cosmic rocket to the Moon was achieved (Lunik 1). The last stage of that rocket of 1472 kg weight without fuel, was provided with a special container inside which was installed a special scientific instrumentation designed for the complex scientific experiments during the investigation of interplanetary space.

With the help of the cosmic rocket, studied were the composition and the intensity of primary cosmic radiation, the magnetic fields of the Earth and of the Moon, the gas component of interplanetary matter, the Sun's corpuscular radiation and registered were micrometeors. A special apparatus for the formation of an artificial sodium comet was also installed in the rocket.

The total weight of scientific and measurement apparatus together with the feed sources and the container (payload) constituted 361.5 kg.

The cosmic rocket, escaping the Earth, became an artificial planet of the solar system with a rotation period around the Sun of about 15 months. Its orbit reaches toward the Mars orbit to a distance about four times nearer than the orbit of the Earth.

The first in the history of mankind flight toward the Moon started on 12 September 1959.

On 14 September at 00 hrs 02' 24" Moscow Time the second cosmic rocket (Lunik II) reached the surface of the Moon.

To ensure hitting the Moon in the absence of the correction of its motion over the portion of the free flight, the rocket's motion at the end of the period of acceleration had to be quite precise. For a reliable hitting the Moon (radius — 1740 km) the deflection of velocity from the assigned could not be more than several meters per second, i.e. of 0.01%, while the variation of the velocity vector in a direction by comparison with the computed one could not exceed one tenth of a degree. The blast off time must have been held up to several seconds.

The actual fact of having hit the Moon attests about the high control system's precision over the active portion, and the perfection of the starting system, together with the highest reliability of the automation.

During that flight to the Moon, investigated were the magnetic fields of the Earth and the Moon, the cosmic radiation with the heavy nuclei in it, the Earth's radiation belts, the gas component of the interplanetary matter and meteor particles.

On 4 October 1959 launched was the third cosmic rocket with an automatic interplanetary station (Lunik III), which, among other investigations, conducted the photographing of the far side of the Moon. Thus, in the course of the IGY, 158 launchings were performed with the view of determining the pressure, atmosphere temperature below 100 km at various times of the year and at various latitudes.

For the study of physical properties of the atmosphere and interplanetary space beyond 100 km. 129 following experiments were carried out :

E X P E R I M E N T S	Number of Launchings
Measurement of the concentration of free electrons in the ionosphere	9
Determination of the ion component of the ionosphere	10
Measurements of the concentration of positive ions in the ionosphere	16
Measurement of electron temperature	6
Measurement of air pressure	18
Taking air samples	2
Registration of particle and micrometeor collisions	18
Registration of the ultraviolet region of the spectrum	7
Measurement of sky brightness	6
Registration of the temperature of air's boundary layer	4
Registration of corpuscular fluxes	8
Investigation of cosmic rays	8
Measurements of electrostatic fields	2
Registration of Sun's X-radiation	2
Study of the composition of primary cosmic radiation	4
Determination of the intensity of the magnetic field	3
Investigation of radiation belts	3
Study of the gas component of interplanetary matter	2
Determination of Moon's radioactivity	1

As a result of investigations by means of meteorological geophysical and cosmic rockets and Earth's satellites, new data on the properties of the atmosphere and of interplanetary space have been obtained, and mutual relationships were established between various physical phenomena, Besides, certain new fundamental discoveries were made.

EARTH'S RADIATION BELTS

One of the prominent results of investigations by cosmic rockets and satellites is the discovery of radiation belts, i.e. of regions of high radiation intensity, consisting of charged particles moving in the Earth's magnetic field. Systematic measurements allowed the establishment of boundaries for these belts, the composition of particles and the radiation intensity [3 – 5]. These radiation zones, their radiation intensity and their distance from the Earth, are indicated in Figures 1 and 2. It has been proven by experiemnts aboard the Sputnik III, that the height of the lower boundary of the inner zone in the Eastern hemisphere is $\sim$ 1500 km, and $\sim$ 500 km in the Western hemisphere (the difference is the result of magnetic dipole displacement relative to the center of the Earth). According to measurement data obtained by that cosmic rocket the boundary of the outer zone is at 15 000 km, and the intensity maximum is observed at 26 000 km. At 55 000 km the intensity of terrestrial radiation is quasi nil. Beginning with the 66 000 km altitude, the intensity of radiations is constant : about 2 part. cm^2/sec.

Measurements have shown, that in the outer radiation zone the radiation intensity is great, but particles have a relatively low energy.

The mean energy of electrons at 40 to 50 thousand km is near 50 keV. In the center of the zone the mean energy is of 25 keV.

The particle intensity in the outer zone at a rather small height may vary in magnitude by about one order.

Protons with energies of the order of 100 MeV have been revealed in the inner zone. According to measurements the stability of radiation intensity in the inner zone is better than $\pm$ 15 percent.

Beyond the magnetic field of the Earth (at more than 65 000 km from the center of the Earth) the charged particle flux is 1800 ± 80 particle/m^2 sec · sterad; the photon flux has the energies of 45 – 450 keV – 3200 ± 100 quanta/m^2 sec · sterad and the photon flux with energy of 0.45 – 4.5 MeV is equal to 1000 ± 100 quanta/m^2 · sec · sterad.

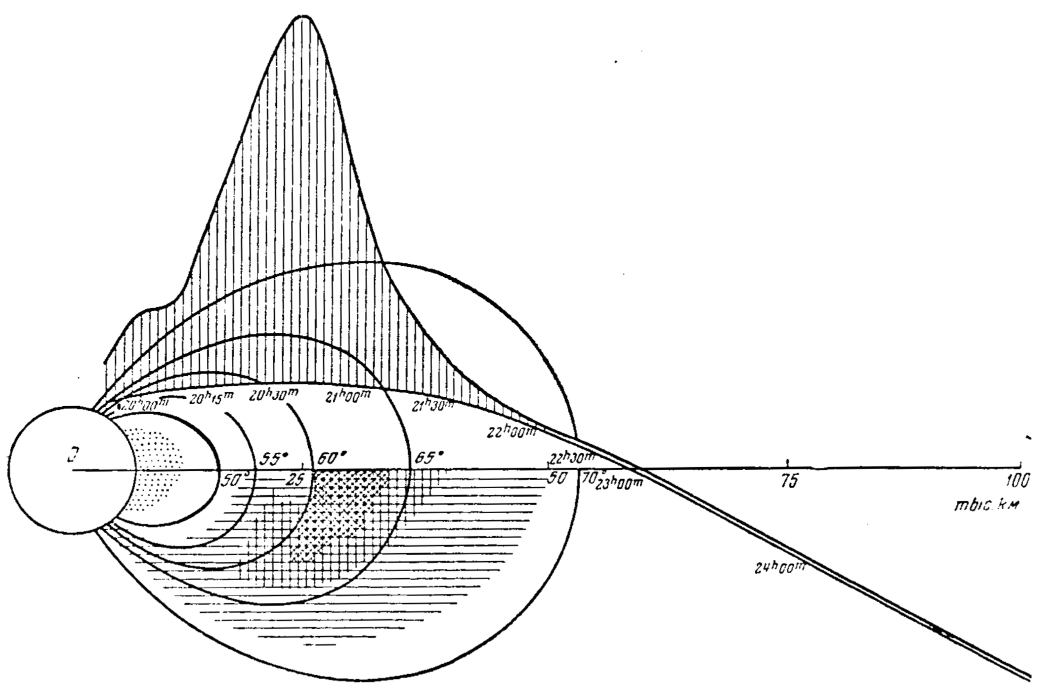

FIG. 1. Trajectory of the rocket in geomagnetic coordinates

The indicated time of flight is Moscow time and the radiation intensity (vertical lines resting on the trajectory). The aggregate ionization is taken as a measure of intensity. Magnetic lines of force are pictured, intersecting the Earth's surface at geomagnetic latitudes 50, 60, 55, 65 and 70° (the magnetic field is a dipole field with geomagnetic pole coordinates 78.5° N and 65° E). Dots indicate the inner zone, dashes – the outer zone. The consistency of shading gives a qualitative representation about the distribution of intensity in the outer zone [3].

Concerning the origin of radiation belts several hypotheses were advanced. The observed spectra and the composition of radiations in the inner zone are well explained by the hypothesis of its origin as a result of neutron decay [4]. Under the effect of cosmic rays originating in space atom nuclei entering in the composition of the atmosphere are disintegrated and neutrons are formed. Near the Earth part of neutrons disintegrates with the formation of electrons and protons. The other part escapes into space. The charged particles with comparatively low energies result trapped in the Earth's magnetic field, where they move, climbing during a long time along the lines of force of the Earth's magnetic field.

The outer radiation zone apparently is the result of solar corpuscular streams' injection into the geomagnetic field.

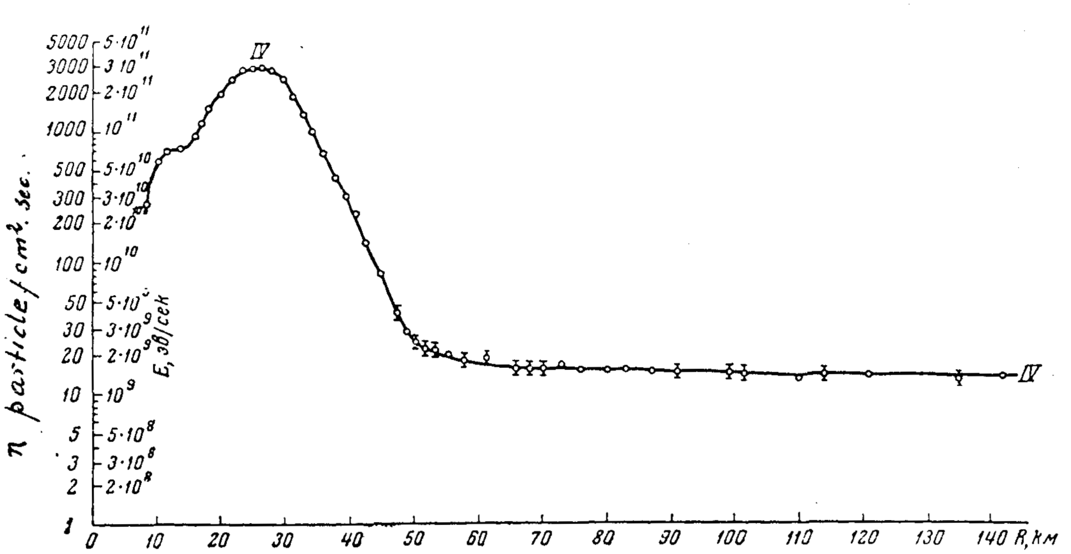

Fig. 2. Total ionization as a function of flight altitude of the cosmic rocket [3].

The corpuscular streams consist of neutral particles and of an equal number of positively and negatively charged particles. Part of the latter is captured by the magnetic field.

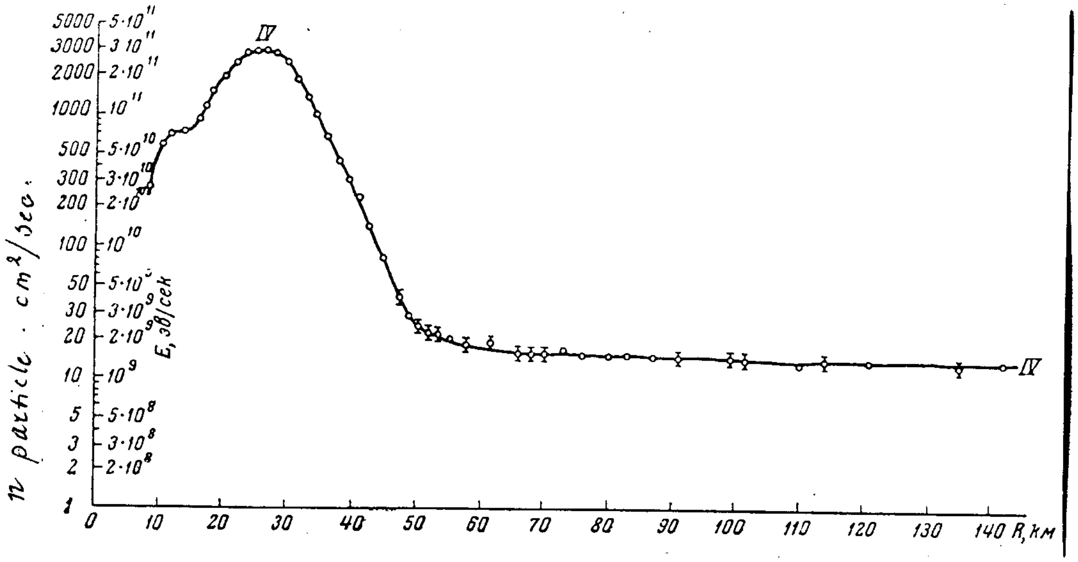

Fig. 2. Total ionization's dependence on the flight altitude of the space rocket [3]

Thanks to current measurements by ion traps on cosmic rockets, a third, outermost radiation belt was detected. It consists basically of comparatively soft electrons with energy above 200 eV. At a distance of 50 000 km the electron flux with $E > 200$ ev, $N < 2 \cdot 10^7$ cm^{-2} sec^{-1}, in the belt region 55 000 km $< R < 75\,000$ km, $N \simeq 2 \cdot 10^8$ cm^{-2} sec^{-1} [6].

It is assumed that this belt if formed as a result of permanent weak corpuscular stream, solar wind interaction with the Earth's magnetic field [7]. An energy redistribution takes place — from protons to electrons — on account of interaction.

Radiation belts change significantly their characteristics depending upon the solar activity.

The detection of radiation belts around the Earth provides the possibility of concluding that any celestial body, having a magnetic field. must have radiation belts. It may be assumed that Mars and Venus also possess significant radiation belts.

Magnetic Field.

Investigations of the Earth's magnetic field led to deductions broadening our representations of its variations. On the basis of the experiments carried out, one may assume that variations of the Earth's magnetic field are apparently caused by the existence in the ionosphere of local current systems, and that the Sun exerts an active effect upon the geomagnetic field.

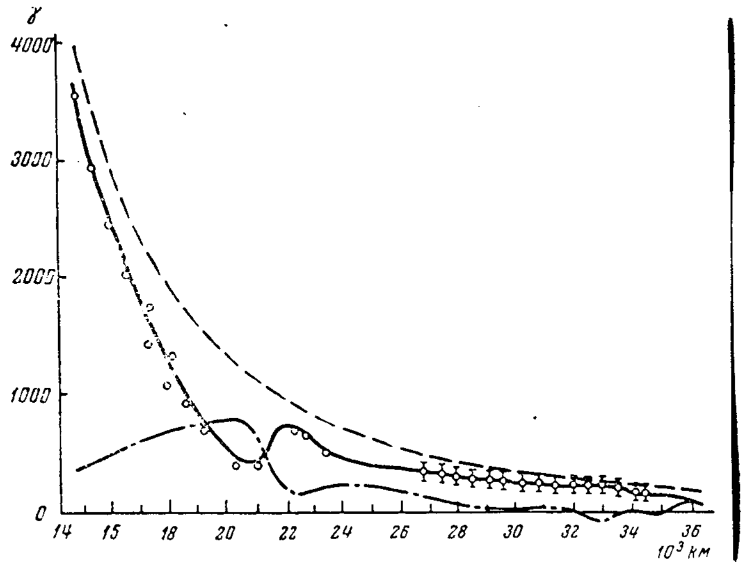

Fig. 3. Magnetic field of the Earth as a function of distance.

Dashed curve — theoretically computed values ; solid curve — measured values of the field ; Dash-dotted curve — difference between the theoretically computed and the measured values of the field.

Fig. 3 shows the variation of the Earth's magnetic field according to theory and its value determined by the cosmic rocket [8, 9].

An anomaly in magnetic field variation is observed at a distance of 21 000 km from the center of the Earth. It begins to rise and reaches the maximum value of 800 γ at the distance of 22 000 km, and then it decreases. One may assume that the observed variations of the magnetic field are linked with the outer radiation zone and may be explained by the superimposition the magnetic field of the Earth of that of the corpuscular zone which has two maxima, respectively at 20 000 and 23 000 km from the center of the Earth (fig. 3). One of the causes of the appearance of the magnetic field of the radiation zone may lie in drift-currents, occurring on account of the drift of charged particles in the magnetic field of the Earth. The variations in the position of the outer radiation zone and its intensity are correlated with magnetic storms and aurorae. The stronger the magnetic storm, the closer to Earth is the maximum of the outer zone'z radiation. The farther from the moment of the magnetic storm, the farther disposed is the maximum from the Earth.

As a result of investigations conducted on the 3rd artificial satellite, new data were obtained on the constant magnetic field of the Earth. Its measurements in the Eastern Siberian anomaly points to deep-seated sources of that anomaly, which is contrary to previous assumptions.

Ionization and Composition of Atmospheric Ions.

Interesting data were obtained on atmosphere ionization. The measurements carried out have shown that the earlier assumed sharply-expressed laminated character (E, F_1 and F_2 - layers) of electron distribution with height in the atmosphere is absent. Electron concentration increases as of about 100 km altitude, reaching a maximum at about 300 km, and then it slowly decreases (fig. 4) . On February 24, 1958 a $1 \cdot 10^6$ cm^2 electron concentration was observed at 473 km, which was only twice as low as that at 300 km. Measurements of positive ion content in the atmosphere to 1000 km permitted to establish that their concentration is near that of electrons. On 15 May 1958 the concentration of positive ions at 795 km was equal to $1.9 \cdot 10^5$ ions/cm^3 [10].

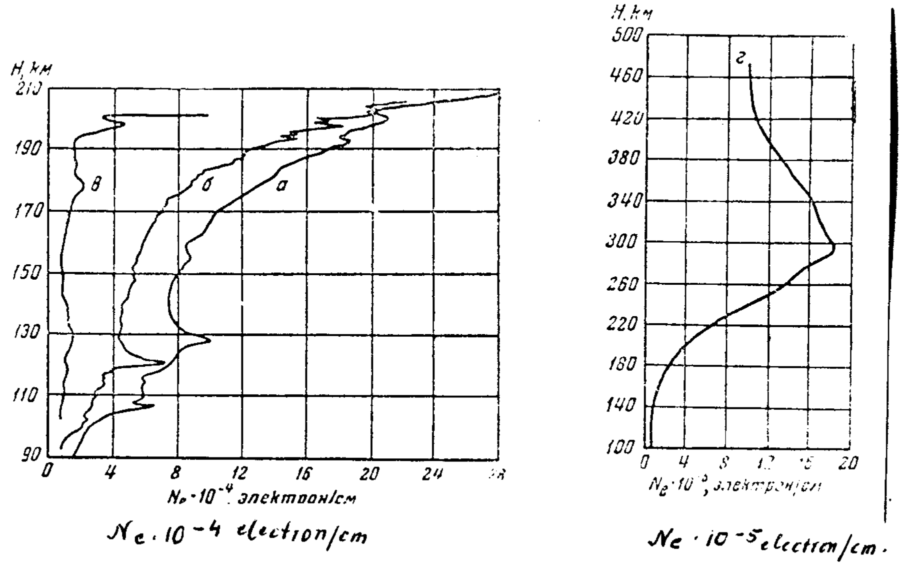

Fig. 4. Distribution with height of electron concentration [10]

a — 06 18 hrs on 16 May 1957 ; б — 06 27 hrs on 25 Aug.1957 ;
в — 19 54 hrs on 9 Sep.1957 ; г — 11 40 hrs on 21 Feb. 1958.

These results also suggest about the slow variation of atmosphere ionization above 300 km altitude.

New data on ion composition in the atmosphere in the 100 — 1000 km altitude range have also been obtained [11].

Investigations have shown that atomic oxygen ions predominate at these heights. The atmosphere composition is nitrogen-oxygen and not hydrogen as was earlier assumed, to at least 1000 km altitude. The composition of the ionosphere varies with altitude and latitude.

Molecular nitrogen N_2^+, nitrogen oxide NO^+, molecular oxygen O_2^+ oxygen isotope $(O^{18})^+$, oxygen atom O^+ and nitrogen atom N^+ ions are observed in the 225 — 500 km altitude range.

Above 500 km the ionosphere consists of atomic oxygen and nitrogen ions. Molecular ions' share there is less than 0.1%.

Density of the Atmosphere.

On the basis of measurements obtained with the aid of manometers, by satellite deceleration, from sodium cloud diffusion etc., the density of the atmosphere was determined to 700 km altitude, and also the temperature and pressure of the atmospheric gas. It resulted that above 200 km the atmosphere density is 5 to 10 times higher than the values earlier admitted on the basis mainly of theoretical suppositions. Thus, on 16 May 1958 there were about $3 \cdot 10^9$ particles/cm^3 at 250 km, and $8 \cdot 10^7$ particle/cm^3 at 500 km [12]. The concentration decrease at these altitudes takes place at a much slower pace than at lower altitudes, where the concentration decreases about 10 times at altitude increase by 10 km (Fig. 5).

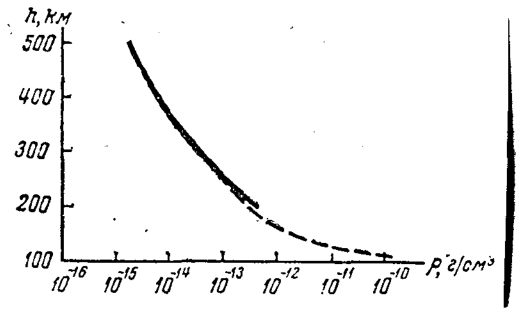

Fig. 5. Density variation with altitude [12]

Solid line — according to manometric measurement data of Sputnik III ; dashed line — according to measurements by means of other Soviet satellites and rockets.

At such high density the gas temperature is also high. At 200 km it reaches 1000° K.

It is established that the atmosphere is not any sort of congealed formation. Its parameters vary as functions of solar activity. Latitude and seasonal variations of temperature and density of the atmosphere have been detected. The atmosphere boundary extends to 2000 — 3000 km above the Earth.

Meteors.

During experiments on rockets and satellites by special instruments — piezoelectric pickups — number of particle collisions and their energy were measured. Collisions of particles with small masses were noted [13] (see Table):

Means of Investigation	Date	Mass of registered particles at v =40km per second	Number of collisions m^2/sec
Sputnik III	15.V 1958	$8 \cdot 10^{-9}$—$2,7 \cdot 10^{-8}$	4—11
	16—17.V 1958		$5 \cdot 10^{-4}$
	18—26.V 1958		$< 10^{-4}$
First Cosmic Rocket	2.I 1959	$2,5 \cdot 10^{-9}$—$1,5 \cdot 10^{-8}$	$< 2 \cdot 10^{-3}$
		$1,5 \cdot 10^{-8}$—$2 \cdot 10^{-7}$	$< 5 \cdot 10^{-4}$
		$> 2 \cdot 10^{-7}$	$< 10^{-4}$
Second Cosmic Rocket . . .	12.IX-1959	$2 \cdot 10^{-9}$—$6 \cdot 10^{-9}$	$< 5 \cdot 10^{-5}$
		$6 \cdot 10^{-9}$—$1,5 \cdot 10^{-9}$	$< 5 \cdot 10^{-5}$
		$> 1,5 \cdot 10^{-8}$	$9 \cdot 10^{-5}$
Third Cosmic Rocket . . .	4.X 1959	10^{-9}—$3 \cdot 10^{-9}$	$4 \cdot 10^{-4}$
	18.X 1959	$3 \cdot 10^{-9}$—$8 \cdot 10^{-9}$	$2 \cdot 10^{-3}$
		$> 8 \cdot 10^{-9}$	$4 \cdot 10^{-4}$

The results of measurements show that near the Earth the density of meteor matter varies.

Corpuscular radiation, Heavy Nuclei.

As a result of investigations corpuscular fluxes with tremendous energies — to several hundreds of keV were registered [14].

The presence of heavy nuclei, with a charge above 30 was revealed in the composition of the cosmic radiation. Their number is about 10 000 times smaller than that of heavy nuclei with a charge above 16 [15]. Unique data were obtained during investigations near the Moon. It was established by experiments on the second cosmic rocket, that the magnetic field of the Moon is at least 400 times less intense than at the Earth's surface.

The radiation intensity measured during the time of rocket's nearing the Moon's surface, at a distance to 1000 km, does not differ from that of cosmic background within 10% limits.

Consequently, one may consider that no zone of increased radiation exists near the Moon.

Therefore, the results of investigations obtained during, the IGY, have broadened our representations about the upper atmosphere and the interplanetary (cosmic) space.

These investigations constitute a new, enormous step forward in our knowledge of physics of phenomena in the upper atmosphere and cosmos. Subsequent investigations should allow the explanation of the origin of the Earth's magnetic field, radiation belts, their interrelation, and the cause of heating of upper atmosphere etc..

Investigations according the IGY Program were conducted during the period of solar activity maximum. It was established that the solar activity influences all processes taking place in the upper atmosphere. For a full understanding of the correlation between phenomena in the upper atmosphere and the solar activity, and for the determination of quantitative links between these processes, it is necessary to extend these complex investigations more particularly during the period of solar activity minimum.

****** E N D ******

Translated by ANDRE L. BRICHANT
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4 July, 1962

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